Improving Autonomous Driving Safety through a better Understanding of Traffic Scenes and of Potential Upcoming Collisions : A Bayesian & Machine Learning Approach (Invited Plenary Speech)

Christian Laugier

▶ To cite this version:

Christian Laugier. Improving Autonomous Driving Safety through a better Understanding of Traffic Scenes and of Potential Upcoming Collisions : A Bayesian & Machine Learning Approach (Invited Plenary Speech). ICARCV 2018 - 15th International Conference on Control, Automation, Robotics and Vision, Nov 2018, Singapore, Singapore. pp.1-15. hal-01969802

HAL Id: hal-01969802

https://inria.hal.science/hal-01969802

Submitted on 4 Jan 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Improving Autonomous Driving Safety through a better Understanding of Traffic Scenes and of Potential Upcoming Collisions :
A Bayesian & Machine Learning Approach

Christian LAUGIER, Research Director at Inria
Inria Chroma team & IRT nanoelec – Also Scientific Advisor for Probayes and for Baidu China
christian.laugier@inria.fr

ADAS & Autonomous Driving

Invited Plenary Speech
ICARCV 2018 – Plenary Forum on the "Impact of AI on Robotics and Computer Vision"
Singapore, November 20th 2018

informatics mathematics

© Inria & Laugier. All rights reserved

NANOELEC.

Autonomous Cars & Driverless Vehicles

- Strong involvement of Car Industry & GAFA & Large media coverage
- An expected market of 500 B€ in 2035… *but Legal & Regulation issues unclear*
- Technologies Validation & Certification *=> Numerous recent & on-going real-life experiments (insufficient) + Simulation & Formal methods (e.g. EU Enable-S3)*

Tesla Autopilot based on Radar & Mobileye
Commercial ADAS product =>tested by customers !

Waymo: Lidars & Dense 3D mapping
Numerous vehicles & 25 000 km/day !

Intelligent Mobility Service

Numerous EU projects in last 2 decades
Cybus experiment, La Rochelle 2012
(EU CityMobil project & Inria)

Drive Me trials (Volvo, 2017)
- *100 Test Vehicles in Göteborg, 80 km, 70km/h*
- *No pedestrians & Plenty of separations between lanes*

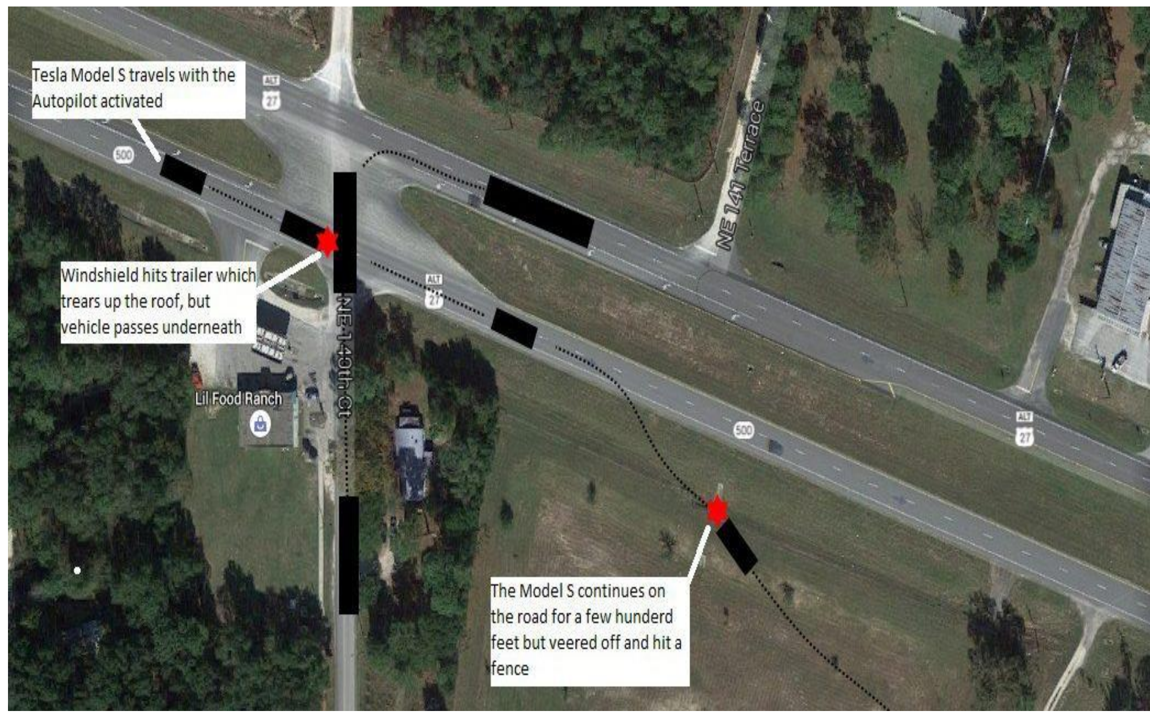
"Robot Taxi" testing in US *(Uber, Waymo)* & Singapore *(nuTonomy)*
⇒ ***Autonomous Mobility Service****, Numerous Sensors + "Safety driver" during testing*
⇒ *Uber: Disengagement every 0.7 miles in 2017, improved now*
⇒ *Waymo 2018 (10 years R&D, 25 000 km/day, 1st US Self Driving Taxi Service in Phoenix*

Millions of miles driven since 2010 (Google, Tesla, Waymo, Uber…)
Several benign & serious accidents in past few years
Safety is still not guaranteed !

Safety issue: *Example of the Tesla accident (May 2016)*

- **Tesla driver killed in a crash with Autopilot active** – *Williston Florida, May 7th 2016*
- **The Human driver was not vigilant** => *A false sense of Safety for the user ?*
- **The Autopilot didn’t detected the trailer as an obstacle**
  - ***Camera*** => *White color against a brightly lit sky ?*
  - ***Radar*** => *High ride height of the trailer probably confused the radar into thinking it is an overhead road sign ?*

Tesla Model S – Autopilot
Front perception:
Camera (Mobileye)+ Radar + US sensors



Safety issue: *Example of the Uber Accident (March 2018)*

- **Self-driving Uber kills a woman in first fatal crash involving pedestrian**
  Temple, Arizona, March 2018
- **The vehicle was moving at 40 mph and didn't reduced its speed before the crash**
  => In spite of the presence of multiple onboard sensors (several lidars, cameras …), the perception system didn't predicted the collision !
- **The Safety Driver didn't appropriately reacted** *(he was not attentive enough)*

=> Two dysfunctions: *Failure of the Perception System & Disengagement process (the safety driver reacted less than 1s before the crash and started to brake after the crash)*

Embedded Perception: Main features

Complex Dynamic Scenes understanding

Situation Awareness & Decision-making

Dealing with unexpected events
e.g. Road Safety Campaign, France 2014

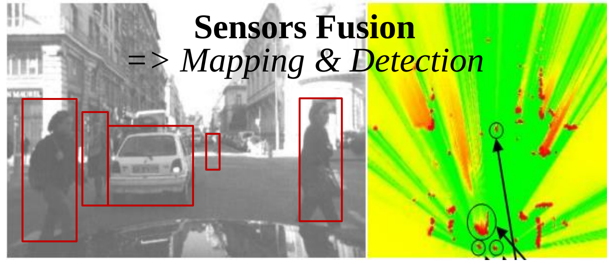
Anticipation & Prediction
for avoiding upcoming accidents

Main features

- ✓ Dynamic & Open Environments => *Real-time processing & Reactivity*
- ✓ Incompleteness & Uncertainty => *Appropriate Model & Algorithms (probabilistic approaches)*
- ✓ Sensors limitations => *Multi-Sensors Fusion*
- ✓ Human in the loop => *Interaction & Behaviors & Social Constraints (including traffic rules)*
- ✓ Hardware / Software integration => *Satisfying Embedded constraints*

Paradigm 1: Embedded Bayesian Perception

Embedded Multi-Sensors Perception
⇒ Continuous monitoring of the dynamic environment



❑ Main challenges

- ✓ *Noisy data, Incompleteness, Dynamicity, Discrete measurements*
- ✓ ***Strong Embedded & Real time constraints***

❑ Embedded Bayesian Perception paradigm

- ✓ *Reasoning about **Uncertainty & Time window** (Past & Future events)*
- ✓ ***Improving robustness** using **Bayesian Sensors Fusion***
- ✓ ***Interpreting the dynamic scene** using **Contextual & Semantic** information*
- ✓ ***Software & Hardware integration** using GPU, Multicore, Microcontrollers…*

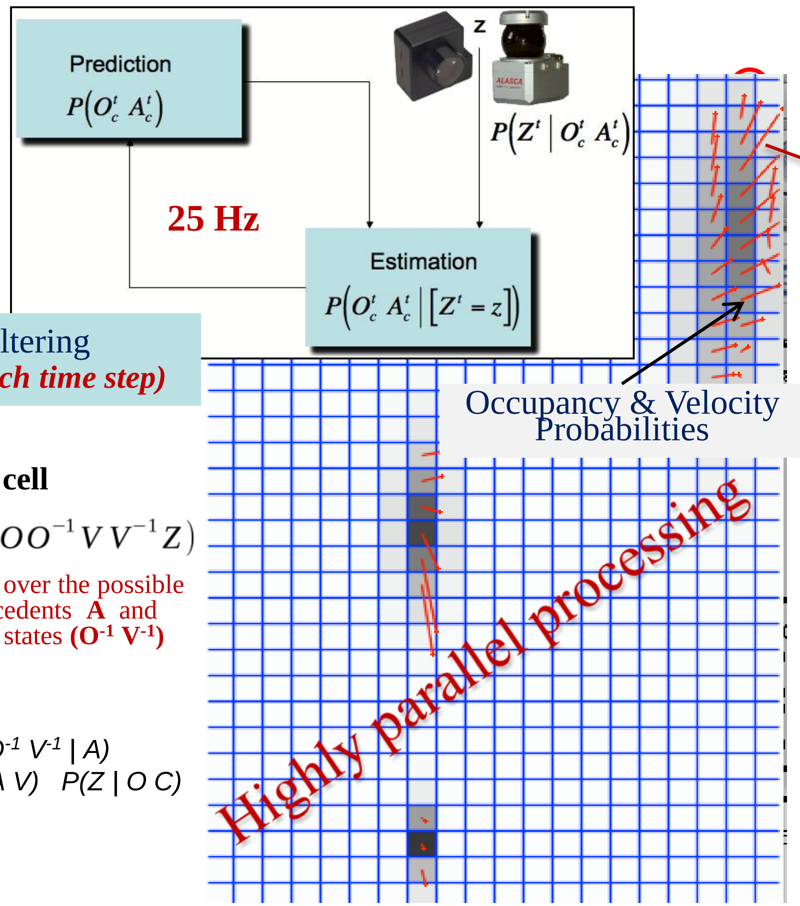
Concept of Dynamic Occupancy Grid

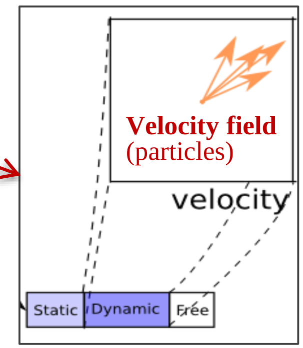
=> A more and more popular approach for Autonomous Vehicles
=> A clear distinction between Static & Dynamic & Free components

Concept of "Bayesian Occupancy Filter" (Inria)

[Coué & Laugier IJRR 05] [Laugier et al ITSM 2011] [Laugier, Vasquez, Martinelli Mooc uTOP 2015]

Sensing *(Observations)*





Bayesian Filtering
(Grid update at each time step)

Solving for each cell

$$P(O\,V \mid Z\,C) = \lambda \sum_{A\,O^{-1}\,V^{-1}} P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z)$$

Sum over the possible antecedents **A** and their states **(O^{-1} V^{-1})**

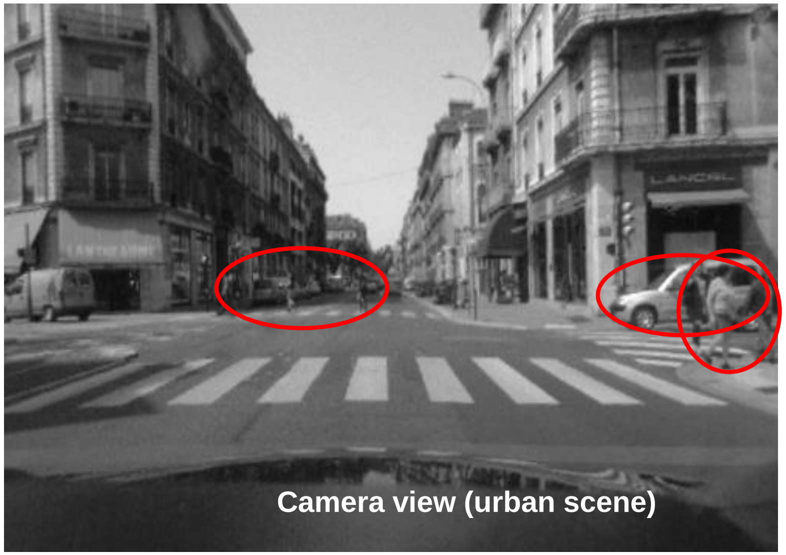
Joint Probability decomposition:

$$P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z) = P(A)\ P(O^{-1}\,V^{-1} \mid A)\ P(O\,V \mid O^{-1}\,V^{-1})\ P(C \mid A\,V)\ P(Z \mid O\,C)$$

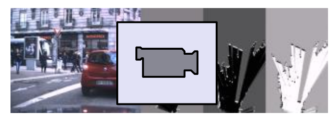
- ***Bayesian Occupancy Filter (BOF)***
  => Patented by Inria & Probayes
  => Commercialized by Probayes
  => Robust to sensing errors & occultation
- ***Used by:*** *Toyota, Denso, Probayes, Renault, EasyMile, IRT Nanoelec / CEA*
- ***Free academic license available***
- ***Industrial licenses: Toyota, EasyMile***

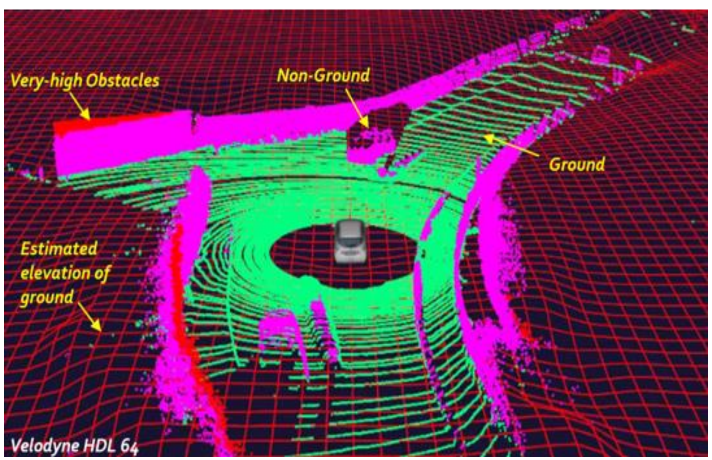
Bayesian Occupancy Filter Approach – *Main Features*

=> Exploiting the dynamic information for a better understanding of the scene

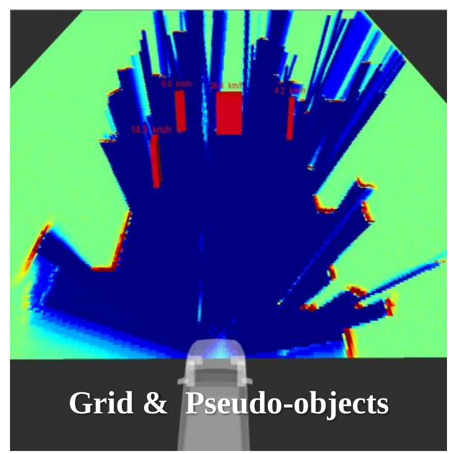


Sensors data fusion
+
Bayesian Filtering
+
Extracted Motion Fields





Ground Estimation & Point Cloud Classification

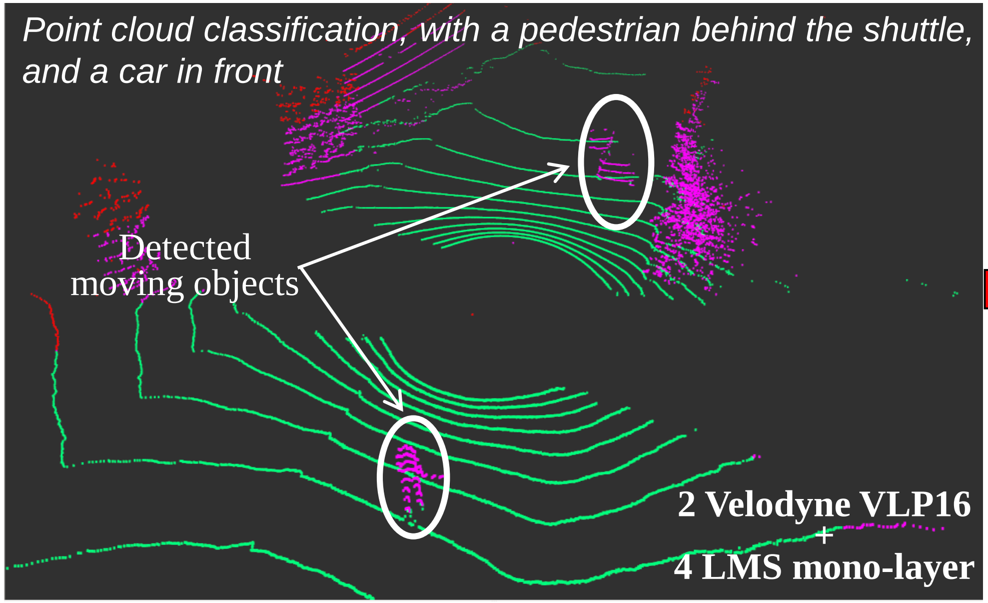


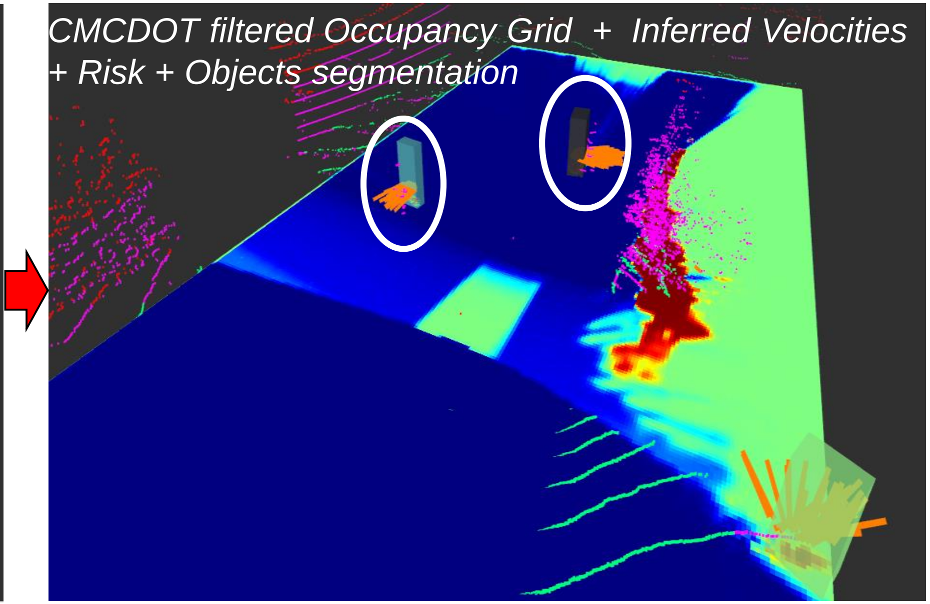
Detection & Tracking & Classification

Integration on a commercial vehicle

- **POC 2017: Complete system implemented on Nvidia TX1**, and easily connected to the shuttle system network *in a few days* (using ROS)

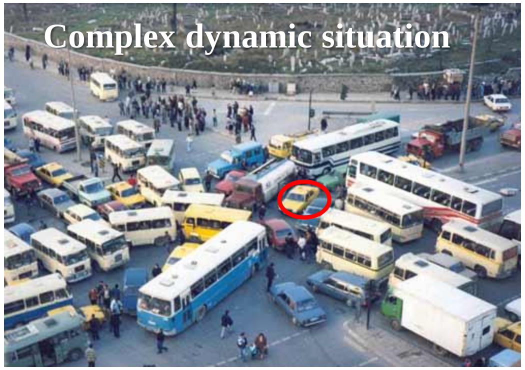
- **Shuttle sensor data** has been fused and processed in **real-time**, with a successful Detection & Characterization of the **Moving & Static Obstacles**
- **Full integration on a commercial product** under development with an industrial company (confidential)

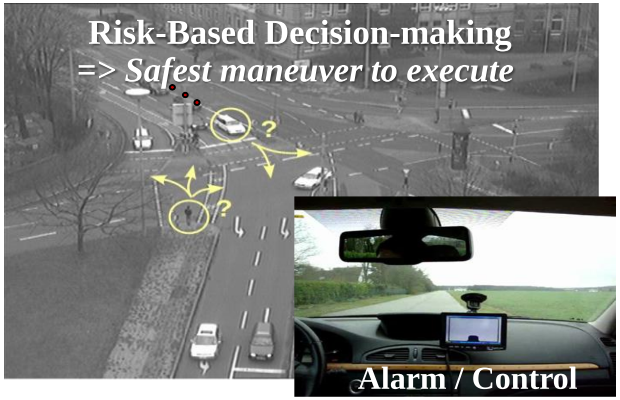




Paradigm 2: Risk Assessment & Decision-making

=> Decision-making for avoiding Pending & Future Collisions





❑ Main challenges

Uncertainty, Partial Knowledge, World changes, Real time

Human in the loop + Unexpected events

❑ Approach: Prediction + Risk Assessment + Bayesian Decision-making

- ✓ *Reason about **Uncertainty & Contextual Knowledge** (using **History** & **Prediction**)*
- ✓ ***Estimate probabilistic <u>Collision Risk</u> at a given time horizon $t+\delta$***
- ✓ *Make **<u>Driving Decisions</u>** by taking into account the **Predicted behavior** of <u>all the observed surrounding traffic participants</u> (cars, cycles, pedestrians …) & **Social / Traffic rules***

Concept 1: **Short-term collision risk** – ***Basic idea***

=> Conservative collision Prediction & Avoidance

[Coué & Laugier IJRR 05]

Autonomous Vehicle (Cycab)

Parked Vehicle (occultation)

Pioneer Results (2005)

Thanks to the prediction capability of the BOF technology, the Autonomous Vehicle "anticipates" the behavior of the pedestrian and brakes *(even if the pedestrian is temporarily hidden by the parked vehicle)*

Short-term collision risk – *Experimental results*

⇒ ***Detect potential upcoming collisions***
⇒ ***Reduce drastically false alarms***

Collision Risk Assessment (video)

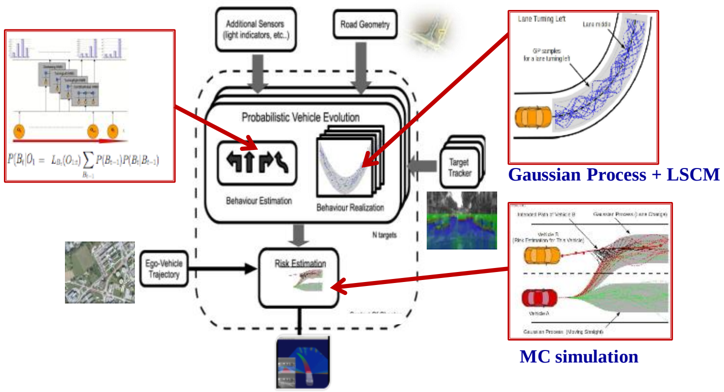
- Yellow => *time to collision: 3s*
- Orange => *time to collision: 2s*
- Red => *time to collision: 1s*

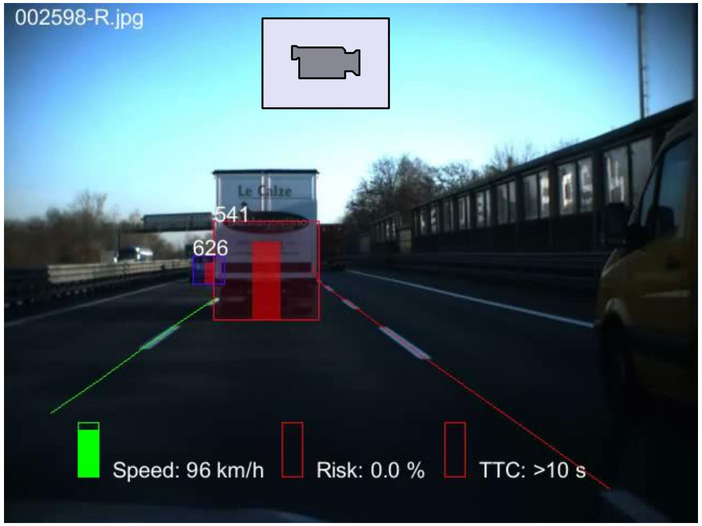
Concept 2: **Behavior-based Collision risk** (Object level)

=> Increased time horizon & complexity + Reasoning on Behaviors

❑ Trajectory prediction & Collision Risk

=> Patent Inria -Toyota - Probayes 2010



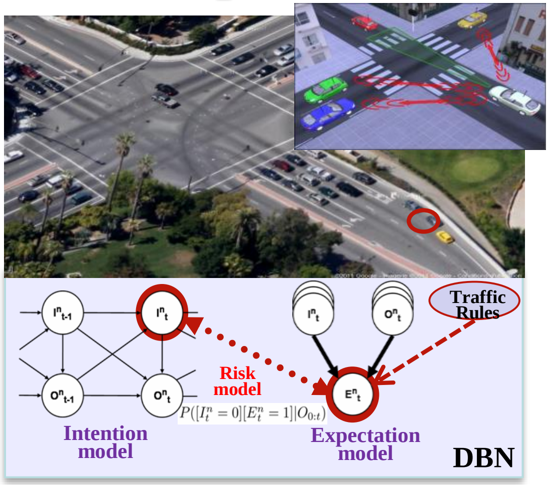


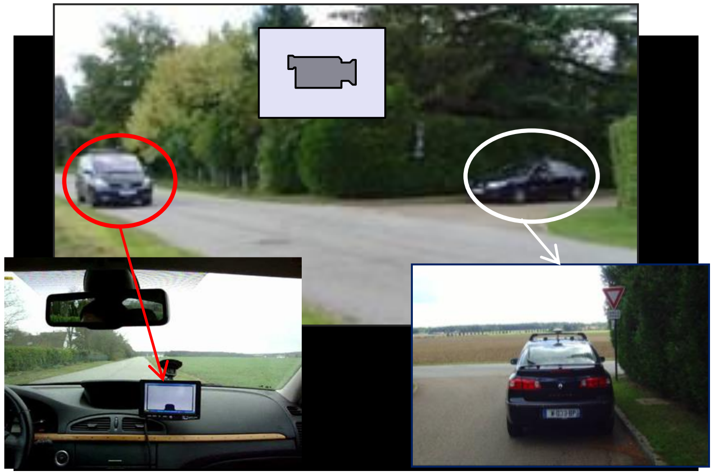
Courtesy Probayes

Cooperation still on-going (R&D contracts + PhD)

❑ Intention & Expectation

=> Patents Inria - Renault 2012 & Inria - Berkeley 2013

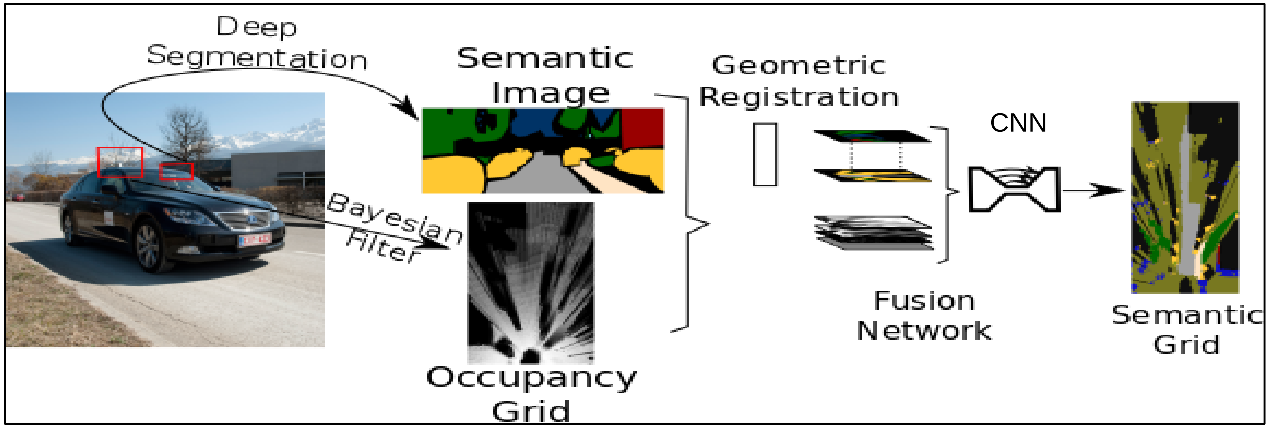


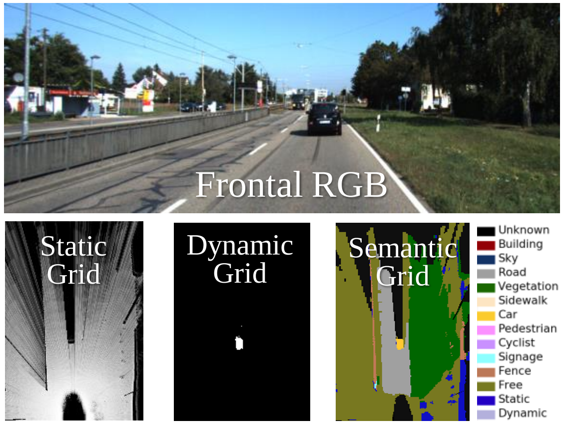


Cooperation still on-going (R&D contracts + PhD)

Paradigm 3: Improvements using Machine Learning

Approach 1: Enrichment of traffic models using Semantic Segmentation

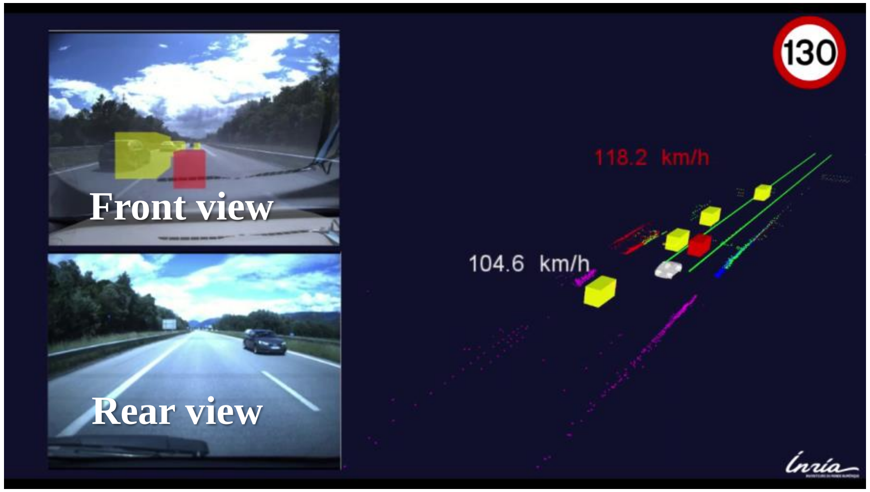




- Inputs: Occupancy Grid, RGB, Sensor Positions
- No need for 3D reconstruction
- **Output: Dense Semantic Grid**
- Patent Inria -Toyota & Publication ICARCV 2018 (session TuDT3 [1])

[1] Semantic Grid Estimation with Occupancy Grids and Semantic Segmentation Networks. O. Erkent, C. Wolf, C. Laugier, ICARCV 2018

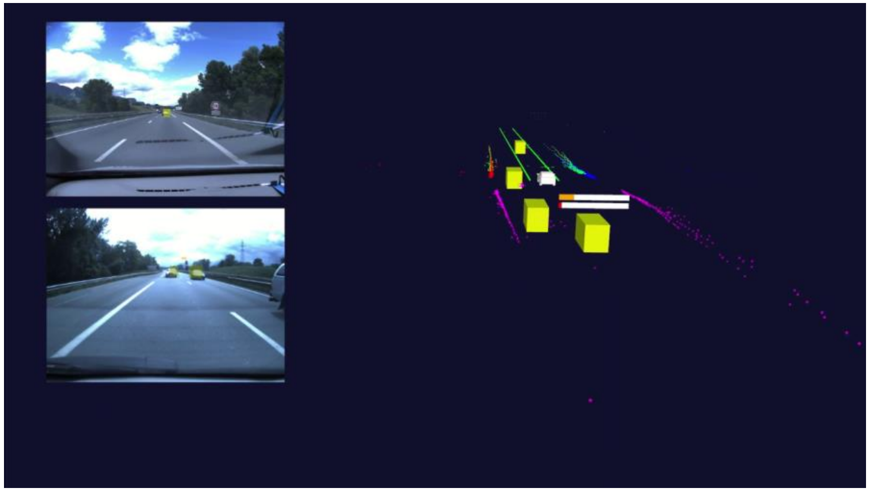
Paradigm 3: Improvements using Machine Learning
Approach 2: Learning Driving Skills for AD (Behaviors & Prediction)



Step 1: Driver behavior modeling

Learn the model parameters automatically from driving demonstrations (real driving data) using Inverse Reinforcement Learning (IRL)

[Sierra Gonzalez et al, ICRA 2018]



Step 2: Motion prediction for Decision-making (AD)

- *A realistic human-like driver model can be exploited to predict the long-term evolution of traffic scenes* *[Sierra Gonzalez et al., ITSC 2016]*
- *For the short/mid-term, both the dynamics of the target and the driver model provide useful information to determine future behaviors* *[Sierra Gonzalez et al., ICRA 2017]*